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RESEARCH MEMORANDUM

RECENT DATA ON CONTROLS

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Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
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INTRODUCTION

The accumulation of information on the characteristics of controls for high-speed airplanes has been rather rapid within recent months. In the present paper an attempt has been made to piece together some of this recent information in a form that might indicate the types of controls to be used advantageously on swept wings (both rigid and flexible), methods and gadgets for balancing trailing-edge flaps, and the characteristics of some all-movable tails.

CONTROLS ON WINGS

Flaps

Since in most swept-wing airplanes the roll control is incorporated within the wing as trailing-edge flaps or spoilers, information on the best locations for effectiveness would be highly desirable. Such information has been obtained for flaps by both wind-tunnel and rocket-model techniques (references 1 to 5). Figure 1 presents some data obtained by the rocket-model technique reported in reference 1. These data, from a systematic test series, show for rigid wings the rolling effectiveness $\frac{pb/2V}{\delta}$ of 30-percent-chord flaps on a swept wing near zero lift. The value of δ in this paper signifies the deflection of the aileron on each wing panel. An interesting point is that the inboard half-span flap is the most effective of the partial-span flaps at high subsonic and supersonic speeds. This fact is well-known but it must be remembered that these data are for rigid wings that do not twist, hence, show the decreased aerodynamic effectiveness of the outer panels of swept wings. The dashed-line curves illustrate the effect of reducing the flap chord to 15 percent. A reduction in effectiveness is shown, as might be expected, for the half-span ailerons in both the inboard and outboard cases. Calculations for estimating control effectiveness can be obtained only by basing such calculations on experimental data whereby the effects of Mach number, aeroelasticity, and so forth may be included. Ideas for basing new methods of calculation may be obtained from references 6, 7, and 8.

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The effect of aeroelasticity upon the effectiveness of half-span ailerons both outboard and inboard is shown in figure 2. For these rocket-model data shown, the wing with the outboard aileron and the wing with the inboard aileron were of comparable stiffnesses, and were reduced to the control effectiveness at sea level and 40,000 feet altitude from the actual test conditions. For the outboard aileron at sea level, roll reversal occurs near $M = 0.8$ and remains negative at supersonic speeds. At 40,000 feet the effectiveness is always positive but becomes small at supersonic speeds. For the inboard aileron at sea-level conditions, roll reversal occurs near $M = 1.1$ and gives near-zero effectiveness up to $M = 1.8$. At 40,000 feet positive effectiveness is obtained through the speed range. The rigidity of the wings, for which these data are presented, would be similar to that for normal construction practices with no extra structural measures taken to increase the twisting rigidity of the wing. Unless costly stiffening procedures are incorporated in the wing design, the effects of aeroelasticity on swept wings at low supersonic speeds make the future of trailing-edge flaps for ailerons look questionable.

Another zero-lift investigation of a swept wing with considerable torsional rigidity yielded information on how to overcome this difficulty with aeroelasticity through the use of spoiler-flap combinations. Figure 3 presents rolling effectiveness data for a particular swept wing with the relative merits of spoiler, flap, and the combination compared for sea-level and altitude conditions. These data represent the characteristics of wing and controls of an actual fighter airplane. For sea level, the ailerons alone suffer roll reversal at $M = 1.0$, the spoiler alone is the most effective at supersonic speeds, and the effectiveness of the combination is reduced considerably by the twisting action of the aileron. The relieving effects of altitude are shown on the right. Here the ailerons alone do not give roll reversal, hence the spoiler-aileron combination adds up to be the most effective.

Spoilers

Inasmuch as spoilers appear to give good roll control, a systematic test series to determine effects of location, height, and so forth were investigated by the rocket-model technique on the same wing as the previous flap investigation. Figure 4 presents some of this information as the helix angle $pb/2V$ developed by spoilers of 5-percent local-chord height for full span, inboard and outboard partial spans, and quarter-span outboard span located at 70 percent of the wing chord. Note, that like the case for flaps, the inboard location is the best for partial-span spoilers. These spoiler data are not for rigid wings, but the spoiler will not twist the wing as much as ailerons. For example, for the same rolling effectiveness $pb/2V$ the spoiler produces about one-third of the twisting moment produced by a flap-type aileron.

The effect of spoiler height on the rolling effectiveness of this swept wing and an unswept wing for full-span spoilers is shown in figure 5. On the left of the figure for the straight wing, is the plotted $pb/2V$ versus spoiler height in fractions of the local chord for various Mach numbers. Test points were obtained at 1/2, 1, 2, and 5 percent heights and show the effectiveness to be quite nonlinear with projection, especially at transonic speeds. Also shown is the decreasing effectiveness with increasing Mach number. On the right for the swept wing, test points were obtained at 2 and 5 percent heights, and show spoilers to be more effective than on the unswept wing above $M = 0.95$ because of the sweep and the thinner section.

Tests of a full-span spoiler on a low-aspect-ratio swept wing in the Langley 9- by 12-inch supersonic blowdown tunnel have shown the effects of angle of attack and spoiler projection on spoiler rolling effectiveness. Some of these data for $M = 1.41$ and $M = 1.96$ are shown in figure 6. The rolling-moment coefficients are reduced for the spoiler deflected on one panel of the complete wing including that area within the fuselage. For the data shown, the full-span spoiler was located at 75 percent chord. The positive h/c means the spoiler was deflected below the wing, and the negative h/c means deflections out of the top surface. Note that the spoiler is effective in producing rolling moment whether deflected on the top or below the wing over the angle-of-attack range tested. At a Mach number of 1.96 the initial values of C_l are less for a given deflection than at $M = 1.41$. Also the effectiveness of the upward deflected spoiler decreases with increasing angle of attack. Subsonic-speed tests in the Langley 7- by 10-foot tunnel of a similar simple spoiler on an aspect-ratio-4 swept wing showed the same angle-of-attack effects and that the upward deflected spoiler became ineffective near 16° of angle of attack (see reference 9).

From the preceding data spoilers appear attractive as a roll control, but there is a drag penalty for their use. An illustration of the drag effects of the inboard half-span spoiler deflected on one panel of the 45° swept wing is shown in figure 7. The bottom curve is the drag coefficient of the wing alone, then the wing plus the 2-percent spoiler and the 5-percent spoiler heights. In evaluating these drag increases, it should be remembered that the 2-percent spoiler gives roll effectiveness equivalent to a 5° aileron deflection on a rigid wing, the spoiler is out but a short time, and favorable yawing moment is produced by the deflection.

BALANCING TRAILING-EDGE FLAPS

Flap-type controls will be included on future aircraft; consequently, the problem of reducing their hinge moments without reducing the effectiveness is an ever recurring difficult problem. The staff of the Langley 7- by 10-foot tunnel has attacked this balancing problem by investigating a variety of devices both old and new on a swept wing mounted on the sidewall of the tunnel which gives data through a Mach number of 1. The balancing methods to be presented are by no means optimum schemes because of the preliminary nature of the investigations but do show which devices bear promise for reducing the hinge moments of trailing-edge flaps. All deflections and hinge moments for flap-type controls were measured perpendicular to the hinge line.

One of the old balance schemes tried were tabs which are reported in reference 10. Results of this preliminary investigation are shown in figures 8 and 9. Shown on figure 8 are the "inset" tab (the standard tab arrangement), and the "attached" tab where the tab hinge line is at the flap trailing edge; and on figure 9, are the "detached" tab where the tab hinge line is nearly a flap chord behind the trailing edge, and a "detached linked" tab or "lifting tab" proposed by the Douglas Aircraft Company. The geometric data of the wing, flap, and tabs are listed on the figures. The data shown on the figures are the lift coefficient due to flap deflection C_{L_δ} for a tab deflection that gives zero hinge moment due to deflection, the hinge-moment coefficient due to angle of attack C_{h_α}, and the ratio of tab deflection to flap deflection to obtain zero C_{h_δ}. The plain-flap data without tabs are shown for reference also.

The inset tab reduces the effectiveness of the flap considerably at transonic speeds, whereas the attached tab does not. The inset tab and the plain flap have similar C_{h_α} characteristics, but the attached tab produces higher negative values of C_{h_α} which would aid in balancing ailerons in rolling maneuvers. The tab deflection required for both arrangements is in the order of two to three times the flap deflection as shown in the bottom curves.

Figure 9 shows the effect of placing the tab on an arm. Here the detached tab gives slightly less effectiveness than the plain control, where the detached linked tab increases the effectiveness. This comes about because the tab surface deflects in the same direction as the flap and a gearing arrangement within the wing converts this moment due to lift into a moment to balance the flap hinge moments. The detached tab produces near-zero C_{h_α}, and the detached link tab produces large negative values of C_{h_α} which for ailerons would be balancing. The detached tab requires deflections of $1\frac{1}{4}$ to $1\frac{1}{2}$ times the flap deflection, where the linked tab requires more deflection, due to its area of about half the detached tab. These results indicate that tabs may be used to balance controls and that such arrangements should be investigated further both statically and dynamically.

Also several arrangements of overhanging balances and horns were investigated by the 7- by 10-foot tunnel staff on this same wing and flap. Some of this information, reported in references 11 and 12, is shown in figures 10 and 11. Shown in figure 10 are the plain flap and the blunt overhang with 50-percent balance area; and in figure 11 two types of horn balances, a normal tip horn and paddle balances above and below the wing ahead of the hinge line at the mid-span location. In figure 10, then, the lift effectiveness of the flap C_{L_δ} is reduced some above $M = 1.0$ by the blunt overhang. The blunt overhang produces positive values of hinge moment due to angle of attack and has decidedly nonlinear hinge moments with deflection as indicated by the two curves for C_{h_δ} at small deflections and large deflections. These data indicate that it may be possible with some arrangement of overhang and control section shape to balance a flap for a given design. In figure 11, the horn and paddle balances change the lift effectiveness of the flap slightly, increasing for the horn and decreasing for the paddles. Both overbalance the flap in terms of angle of attack as shown by the positive C_{h_α} values with the paddles giving a more uniform variation at transonic speeds. Both horn and paddle arrangements had a balancing effect on hinge moment due to deflection as might be expected for balance areas involved.

A new method of actuating flap controls by means of an aerodynamic servo-vane control has been devised by Mr. W. H. Phillips of the Langley Laboratory and reported in reference 13. This so-called servo-vane control system is illustrated in figure 12. A movement of the control stick causes the vanes, which are in a spanwise torque tube, to project from the surface of the wing as shown by the rear view of the wing at the top of the figure. Drag force on the vanes then causes the tube to rotate about an axis parallel to the control surface. This rotation, through the gearing, causes rotation of the control surface so that when the vanes blow back the control surface deflects in the same direction as the projection of the vane. With such a system flap-type controls may be operated with a relatively small control force. The effectiveness of this servo-vane system is shown as the incremental lift coefficient at $\alpha = 0^\circ$ due to a vane deflection resulting in 10° flap deflection as compared with the incremental lift coefficient due to the flap alone deflected 10°. These data from the 7 by 10 bump show the vane- or spoiler-flap combination to be more effective than the flap alone. Shown on the right are the flap angles resulting from deflection of the vanes at Mach numbers of 0.6, 0.9, and 1.0. These data indicate a nonlinear variation of flap deflection with vane angle at $M = 0.6$ and $M = 0.9$ and decrease in servo power of vane at $M = 1.0$.

ALL-MOVABLE TAILS

Recent tests of missile configurations by the rocket-model technique (references 14 and 15) have given data on a 60° delta plan form which may be viewed in the light that these results could apply as airplane pitch controls whether all-movable or flap type. A comparison of some of this information is shown in figure 13. Shown are an all-movable control, a large flap control, and an all-movable tip control. Shown on the left is the lift effectiveness of the controls C_{L_δ}. In thinking of this C_{L_δ} as lift produced (or required) on the tail, indications are that an all-movable tail would be required since C_{L_δ} is large for the all-movable surface (the solid line) as compared with the flap and the movable tip. On the right are the hinge-moment-coefficient characteristics of these controls. These data show that the all-movable controls show promise of balancing out the hinge moments due to both angle of attack and deflection, whereas the flap develops large hinge moments, and increasing the flap area to increase the effectiveness would only aggravate the control problem. It is known that, at larger angles of attack, the balancing of all-movable deltas is not as good, but by linking the flap on to the all-movable surface adequate balance characteristics may be obtained.

An example of combining the aerodynamics of an all-movable tail with that of a flap is the type of "flying tail" devised by the Grumman Aircraft Engineering Company for the XF10F airplane. Figure 14 shows rocket-model results of a tail-alone model of this free-floating tail. The scheme of how the tail operates is shown on the right of the figure. This entire configuration rotates freely about the pivot, and the control stick is directly connected to the bow plane or canard surface δ_c which is used for positioning the tail to various deflections δ aerodynamically. The main surface is equipped with a trailing-edge flap which is linked as a leading-edge flap. For this test the flap deflection equalled the deflection of tail in the same direction. The pivot point of the tail was such that without the flap the tail would be unstable for the subsonic center-of-pressure location. The flap moment supplies the balancing action at subsonic speeds. At supersonic speeds the center of pressure moves over the pivot point, the flap loses some effectiveness, and the tail is slightly more stable or stiff than at subsonic speeds. Trim changes on this tail, then, do not affect the motion of the airplane, only the stick force and position which are the result of the linked-flap moments on the canard trimming position. This effect was found to be very small.

The damping characteristics at two trim positions of this free-floating tail are shown on the upper left of the figure as $C_{m_{\dot{\delta}}}$ the rate of change of pitching moment with rate of deflection. Note the very narrow region just under $M = 1.0$ where the tail lacks damping in pitch. It appears that a damper may be adequate in overcoming this singular lack of damping. On the lower left is shown the lift effectiveness of the tail C_{L_δ}. The value of C_{L_δ} is always greater than 0.06 indicating good effectiveness through the speed range. The effectiveness of the canard or bow plane is shown as $\Delta\delta/\Delta\delta_c$, that is, the tail deflection per unit aerodynamic servo deflection. No variations of $\Delta\delta/\Delta\delta_c$ were encountered over the speed range, which shows the front surface to be adequate in trimming the tail. This type of tail needs more investigating, inasmuch as there are many combinations of linkages, aerodynamics, and downwash fields.

Another type of all-movable tail is one of swept plan form. If a swept-wing plan form is adapted for an all-movable tail the hinge moments may be reduced considerably by sweeping the hinge line. This scheme is shown in figure 15. Tests in the Langley 7 by 10 tunnel on the bump of this swept wing with the hinge line normal to the air stream (reference 16) showed that the centers of pressure move outward as well as rearward with increasing airspeed as indicated by the dots on the sketch of the wing plan form. It is seen that, if the hinge line were made to lie along the outward movement of the centers of pressure, reduction in hinge moments would be possible. Such a test was made on the 7 by 10 side wall where the hinge line was swept 45.6° and at 23.5 percent of the chord. The results of the tests are shown on the upper left as a plot of the total hinge-moment coefficient that results from a desired tail lift coefficient of 0.4 for the cases of the swept and unswept hinge lines. The test points are actual data points and the faired lines also indicate about how well these characteristics can be calculated knowing the spanwise and chordwise center-of-pressure variations. Note that if both hinge lines are designed to give zero C_h at subsonic speeds that because of the outward movement of the center of pressure the swept hinge has considerably less hinge-moment coefficient at transonic speeds than the unswept hinge line. This type of tail with a swept hinge line appears to be a "natural" for the addition of a linked tab to compromise hinge moments at other tail lift coefficients, and needs further investigation along these lines.

RÉSUMÉ

To summarize briefly, recent experimental results were presented which indicated that:

1. For partial-span flaps the inboard location is the best for ailerons, but the effectiveness is seriously reduced by aeroelastic effects.

2. Spoilers appear as a promising means of roll control.

3. Plain flaps may be balanced without reducing the effectiveness by means of tabs, horns, and spoiler-flap combinations.

4. All-movable tails of delta and swept plan forms appear particularly promising both from the effectiveness and control-force standpoints.

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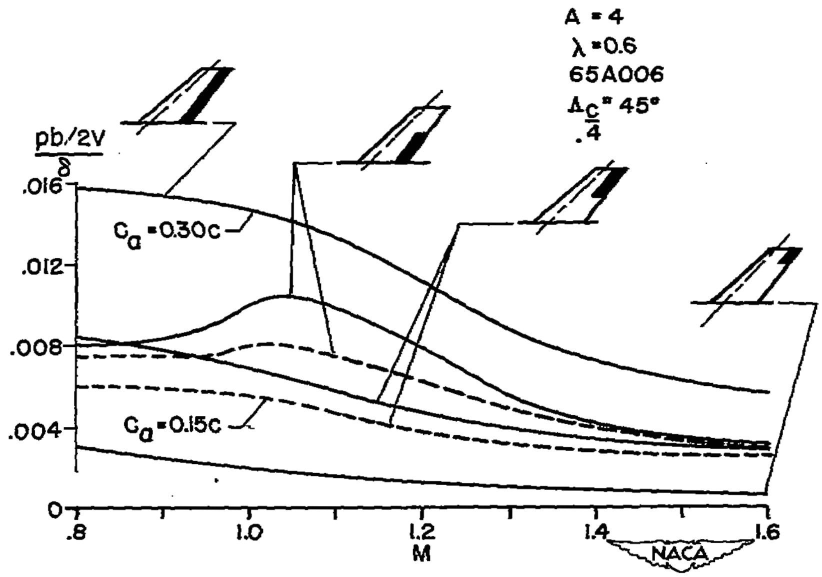

Figure 1.- Effect of spanwise location of flap-type ailerons on the rolling effectiveness of a rigid sweptback wing.

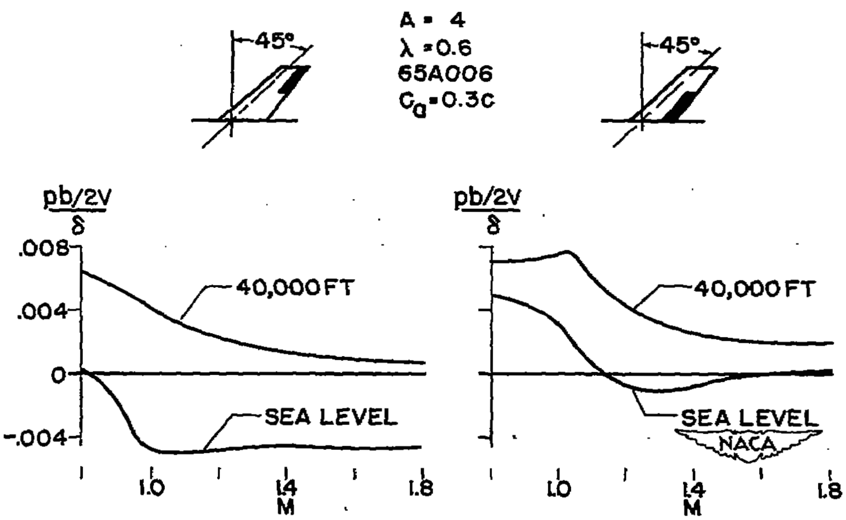

Figure 2.- Effect of aeroelasticity on the rolling effectiveness of a sweptback wing with half-span outboard and inboard flap-type ailerons.

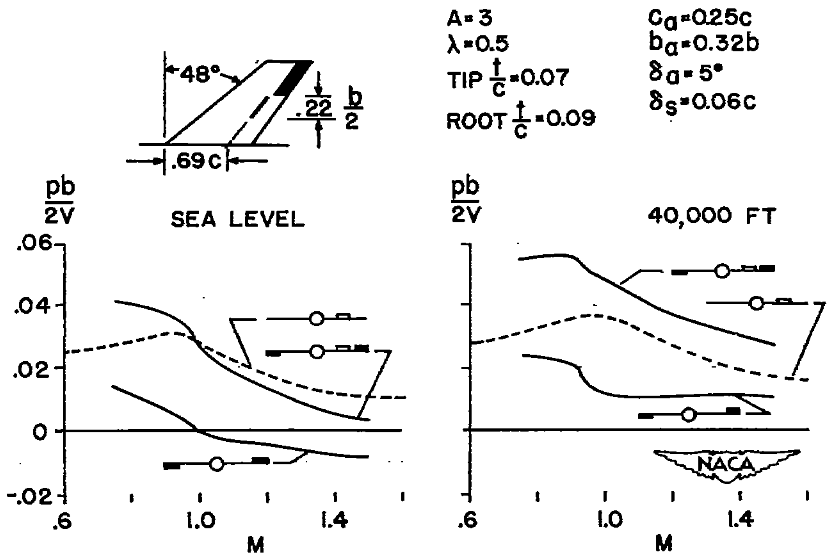

Figure 3.- Rolling effectiveness of flap-type ailerons, spoiler, and spoiler-flap combination for a particular swept wing with increased torsional rigidity.

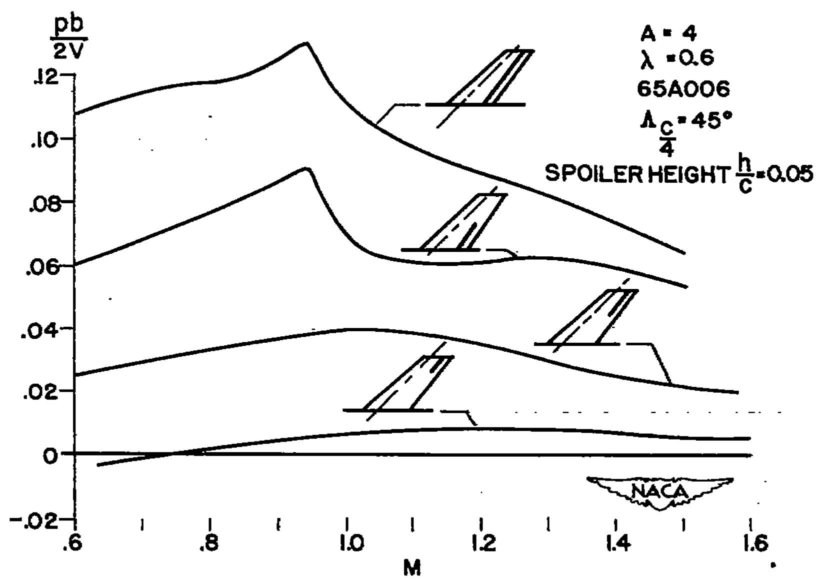

Figure 4.- Effect of spanwise location of spoiler at 70 percent chord on the rolling effectiveness of a sweptback wing.

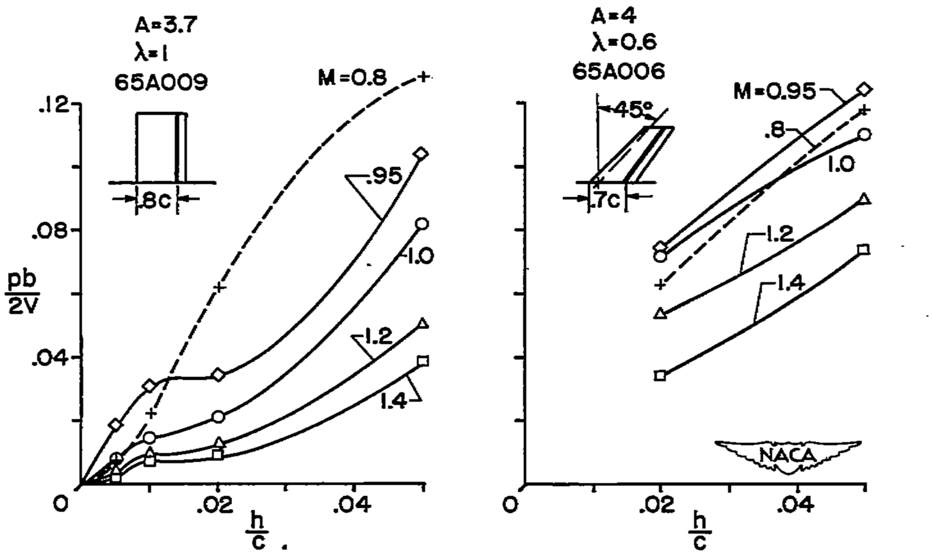

Figure 5.- Effect of spoiler height on the rolling effectiveness of a straight and swept wing.

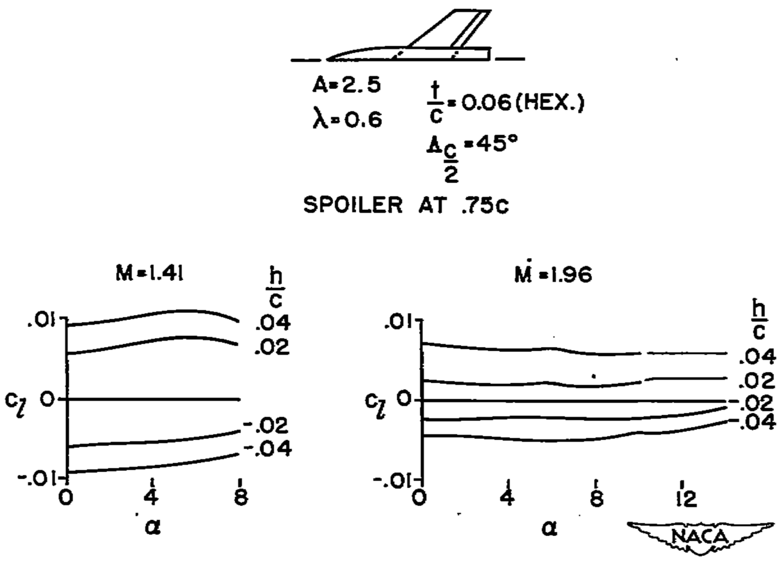

Figure 6.- Effect of angle of attack on the rolling effectiveness of a full-span spoiler on a low-aspect-ratio swept wing at supersonic speeds.

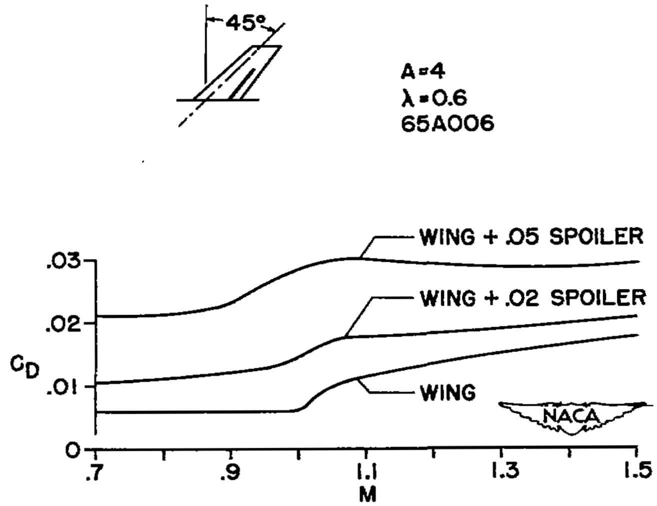

Figure 7.- Drag-coefficient characteristics of an inboard half-span spoiler on a swept wing.

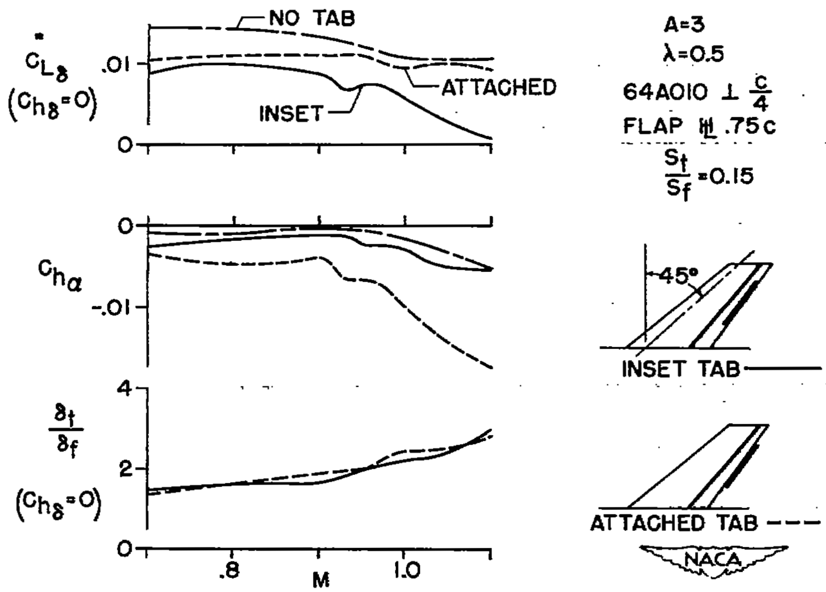

Figure 8.- Effects of an inset and of an attached tab on the aerodynamic characteristics of a full-span flap.

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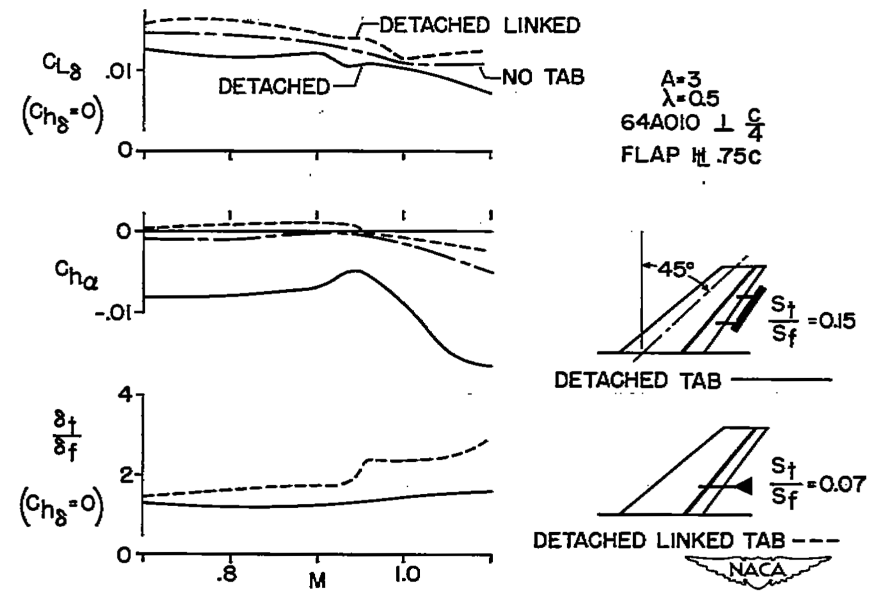

Figure 9.- Effects of a detached and a detached linked tab on the aerodynamic characteristics of a full-span flap.

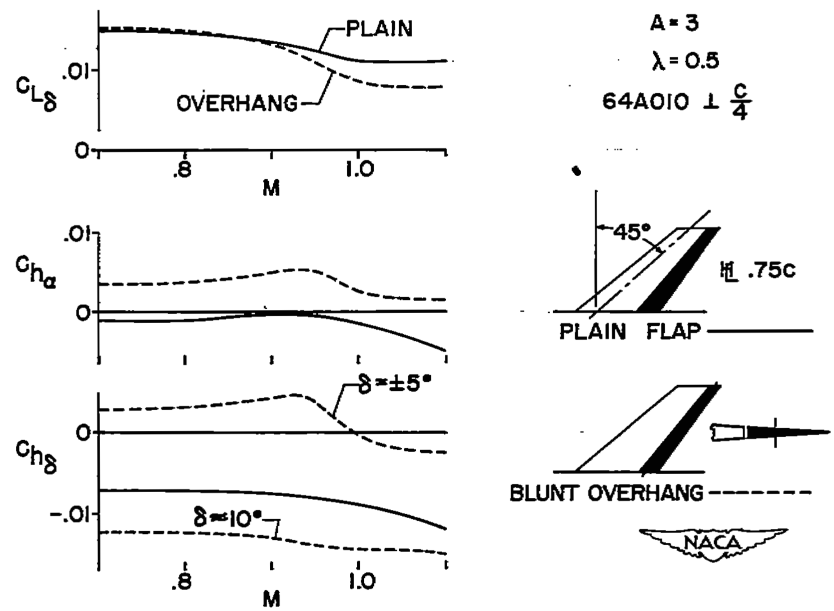

Figure 10.- Effects of blunt overhang of 50-percent balance area on the effectiveness and hinge-moment characteristics of a full-span flap.

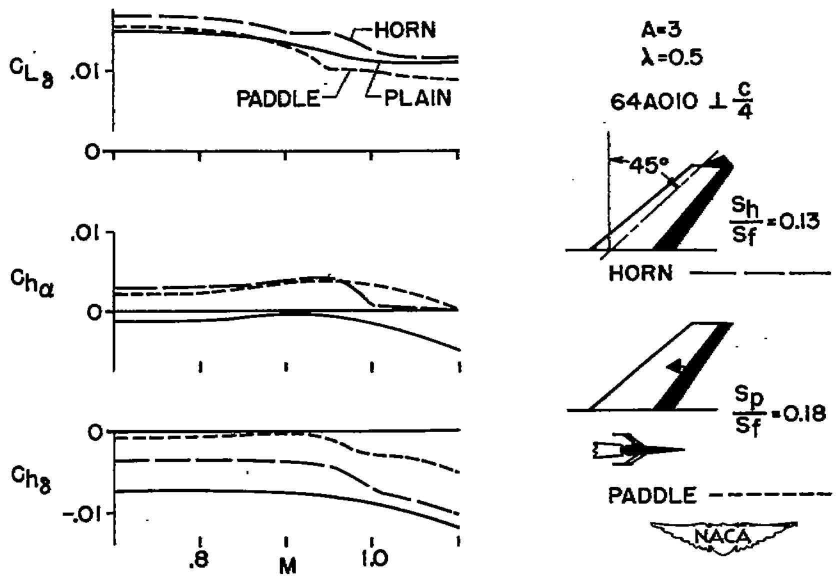

Figure 11.- Effects of a horn and paddle balances on the effectiveness and hinge-moment characteristics of a full-span flap.

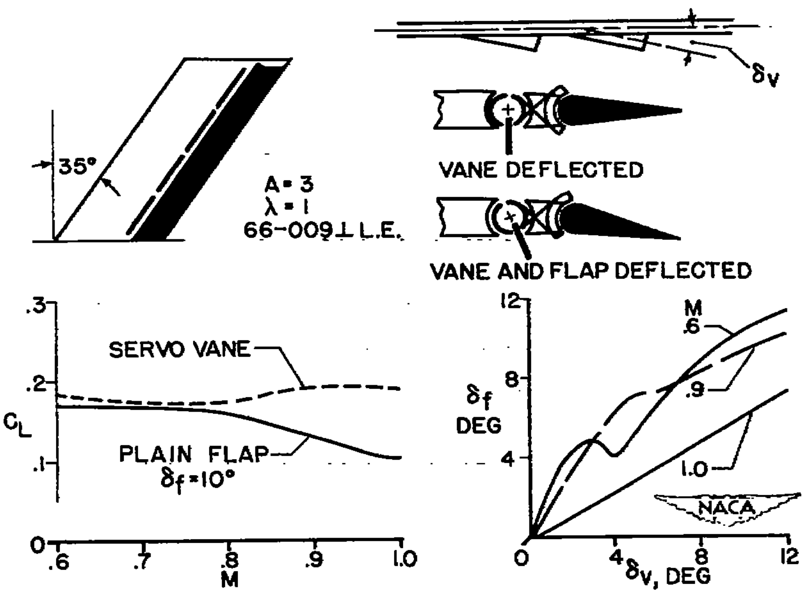

Figure 12.- Aerodynamic characteristics of a swept wing with a flap operated by a series of servo-vanes located ahead of and geared to the flap.

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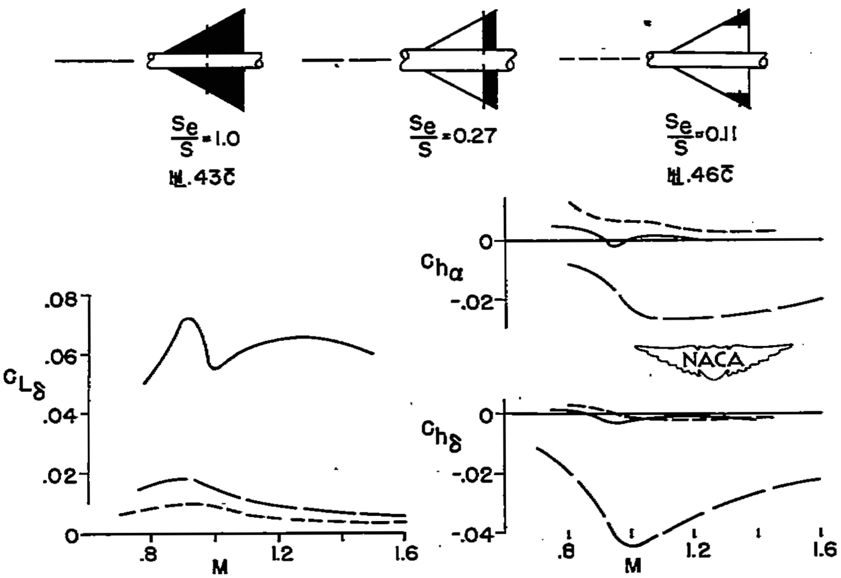

Figure 13.- Effectiveness and hinge-moment characteristics of all-movable, flap, and movable-tip controls on a 60° delta wing.

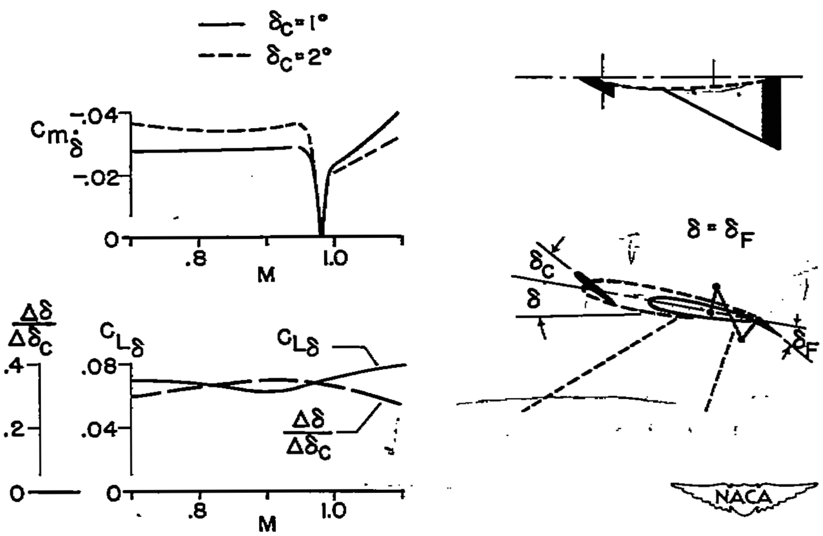

Figure 14.- Aerodynamic characteristics of an all-movable free-floating tail that is positioned by a forward surface.

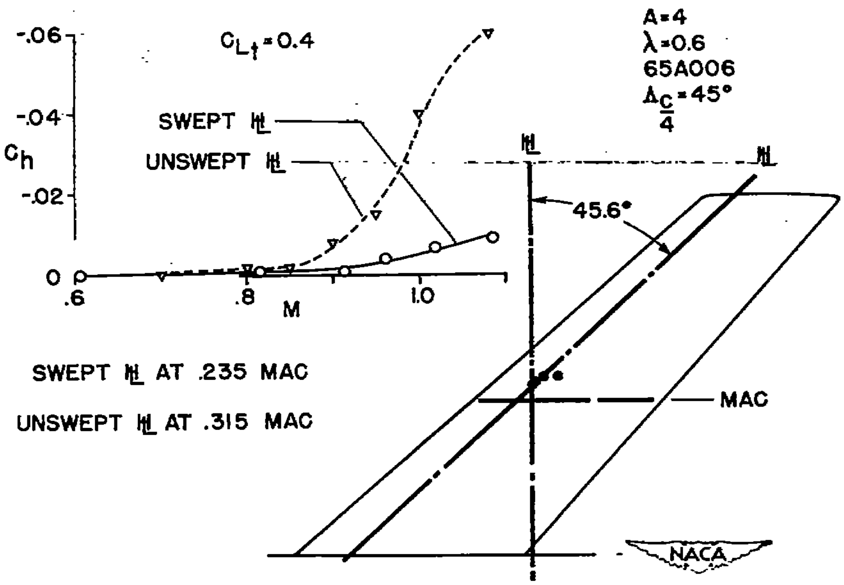

Figure 15.- Effect of sweeping the hinge line on the hinge-moment characteristics of an all-movable tail of swept plan form.

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SECURITY INFORMATION

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